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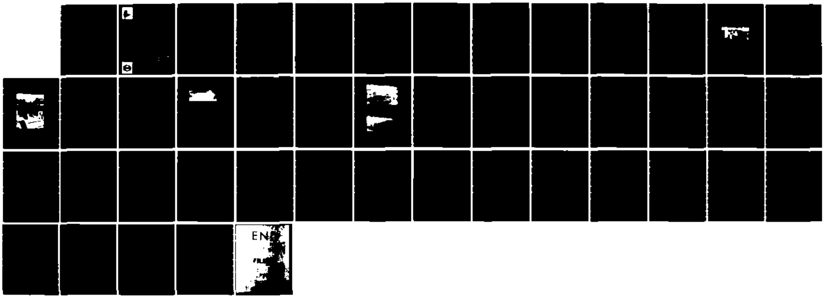

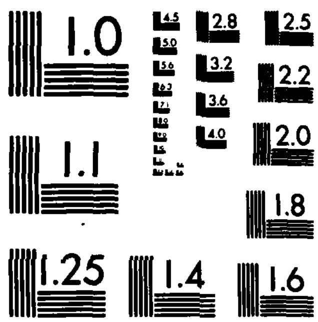

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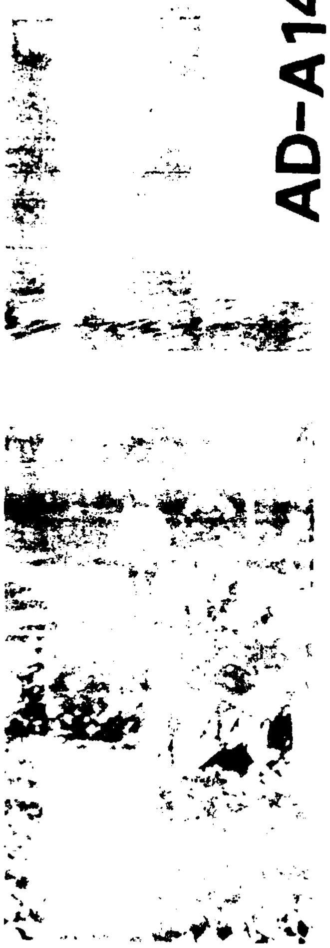

TECHNICAL REPORT A-78-3

MECHANICAL HARVESTING OF AQUATIC PLANTS

Report 3

EVALUATION OF THE LIMNOS SYSTEM

by

James L. Smith

Environmental Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

May 1984

Report 3 of a Series

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The U. S. Army Engineer District, Jacksonville, is continuing their efforts toward instituting environmentally compatible, large-scale aquatic plant control and management programs. The Jacksonville District requested that the U. S. Army Engineer Waterways Experiment Station continue their efforts toward implementing an aquatic plant mechanical control system. The program was devoted to: (a) defining a conceptual framework and acquiring engineering data for developing performance criteria for selected functions inherent in

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mechanical harvesting, (b) soliciting concept designs from industry, and (c) purchasing a mechanical system(s) for control of aquatic plants. This report describes the field experiments conducted and the engineering data collected.

This report briefly describes (b) and (c) above. Requests for Proposals for concept designs from industry were issued in January 1978 with delivery of the Limnos Mechanical Harvesting System being completed in July 1979. System operational tests were conducted on the Withlacoochee River in central Florida during the summer of 1979. Plants harvested were primarily topped-out hydrilla with small amounts of waterhyacinth.

The Limnos Mechanical Harvesting System consists of a separate cutter machine; a harvester, which includes a gathering and conveyor pickup unit and a processor; and two transport tank barges.

Productivity of the cutter unit was evaluated separately and in conjunction with the harvester. Tests were conducted with the harvester with the tank barges to remove the plant material from the water and also without the barges, which allowed the processed plant materials to be discharged directly into the water body. High productivity of the harvester in dense hydrilla (and waterhyacinth mixtures) required reducing the width of cut of the plant material or using 18-ft cuts at two depths (3 and 6 ft). This procedure limited the mass of material that had to be handled by the harvester.

Several potential areas requiring additional research were identified as a result of these tests: improved procedures for evaluating mechanical harvesting machines, and possible improvements to the Limnos harvester system to allow higher productivity.

PREFACE

This study was conducted at the request of the U. S. Army Engineer District, Jacksonville, and the Office, Chief of Engineers, which provided funds under authorization 96X4902. The study was conducted by personnel of the Environmental Systems Division (ESD), Environmental Laboratory (EL), U. S. Army Engineer Waterways Experiment Station (WES), under the general supervision of Mr. Bob O. Benn, Chief, ESD. Mr. J. Lewis Decell was Program Manager, Aquatic Plant Control Research Program, EL, and Dr. John Harrison was Chief of EL. Mr. H. Wade West was the Project Engineer for WES work. Messrs. West, T. D. Hutto, P. A. Smith, and C. E. Stevens, WES, and Mr. John Neil and staff, Limnos Limited, Toronto, Canada, were responsible for the conduct of the field tests; this report was written by Dr. James L. Smith, EL.

Acknowledgement is made to Mr. Joe Joyce, Chief, Aquatic Plant Control Section, and Messrs. Jim McGehee and Dave Bowman, U. S. Army Engineer District, Jacksonville, for their equipment and technical support during the field test. Acknowledgement is also made to Mr. Roy Smith, Floral City, Fla., for his operational support.

Commanders and Directors of WES during the conduct of the study and the preparation of this report were COL Nelson P. Conover, CE, and COL Tilford C. Creel, CE. Technical Director was Mr. F. R. Brown.

This report should be cited as follows:

> Smith, J. L. 1984. "Mechanical Harvesting of Aquatic Plants; Report 3, Evaluation of the Limnos System," Technical Report A-78-3, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
acres	4,046.856	square metres
feet	0.3048	metres
feet per second	0.3048	metres per second
gallons (U. S. liquid)	0.003785412	cubic metres
horsepower (500 ft-lb/sec)	745.6999	watts
inches	25.4	millimetres
miles per hour	1.609344	kilometres per hour
miles (U. S. statute)	1.609344	kilometres
pounds (mass)	0.45359237	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
square miles	2.589988	square kilometres
tons (2000 lb mass)	907.18474	kilograms
tons (2000 lb mass) per acre	0.2241702	kilograms per square metre

MECHANICAL HARVESTING OF AQUATIC PLANTS

Report 3

EVALUATION OF THE LIMNOS SYSTEM

PART I: INTRODUCTION

Background

1. As part of the Corps of Engineers Aquatic Plant Control Research Program (APCRP), the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss., is studying the feasibility of using mechanical harvesting systems alone or to augment other methods (e.g. biological and chemical) to manage problem aquatic plants in water bodies of interest to the Corps of Engineers. The overall goal is the development of a variety of techniques and equipment that can be tailored to the wide range of environmental conditions in which most problem aquatic plants are found.

2. This report, third in a series dealing with mechanical harvesting, describes field tests of the Limnos Mechanical Harvesting System. The Limnos system was selected by WES for the Jacksonville District on the basis of responses to Requests for Proposals (RFP's) to develop a system for harvesting submersed aquatic plants. A "Statement of Work" from the above RFP is given in Appendix A. These tests were conducted in central Florida on the Withlacoochee River by the manufacturer of the system (Limnos Ltd.) and personnel of the WES, in July and August 1979.

3. It was originally intended that the productivity of the Limnos harvester system be correlated with the in situ aquatic plant density. However, it was not possible to measure the in situ plant density due to the lack of a reliable aquatic plant sampling device. Therefore, plant density values discussed in this report are based on the quantity of plant material loaded into the barges, not the in situ density. Plant density values given in this report should be considered on a relative basis only.

4. Previous WES research dealing with field evaluation of mechanical control systems has been documented in the first two reports of this

series.*,** The report by Culpepper and Decell involved the field evaluation of the Aqua-Trio system. Using this system, plants were cut and removed from the water by the harvester. When the storage capacity of the harvester was filled, the plants were transferred to a barge that transported them to shore. On the shore, the plants were moved from the barge into a conveyor that loaded them onto trucks for transport to the disposal area. The Aqua-Trio system is similar to other commercially available machines in that plants are cut and removed from the water by a single harvester unit and handled without processing or changing their properties in any way.

5. Smith reported the results of a series of tests designed to determine practical cutting rates for submersed aquatic plants. In addition, evaluations were made of the feasibility of using natural forces (water currents) to move plant material and of pushing and rafting plant materials mechanically. The requirements for land storage when plant disposal was by natural decomposition were also determined. A major objective in the research reported by Smith was to reduce the overall energy requirements for mechanical removal of aquatic plants.

Purpose and Scope

6. The purpose of the study described in this report was to evaluate the productivity of the Limnos Mechanical Harvesting System in a typical field situation in the Jacksonville District. Since this system is an experimental prototype and not an off-the-shelf production harvesting system, no attempt has been made in this report to estimate normal operating costs. Most of the research tests were conducted in hydrilla, although a few tests were conducted in areas having both hydrilla and waterhyacinth. The mechanical system and/or components of the system were evaluated as follows:

- a. Productivity of the cutter machine in terms of the area covered per unit time.

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* Culpepper, M. M. and Decell, J. L. 1978. "Mechanical Harvesting of Aquatic Plants; Report 1, Field Evaluation of Aqua-Trio System," Technical Report A-78-3 (in 2 vols), U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

** Smith, P. A. 1980. "Mechanical Harvesting of Aquatic Plants; Report 2, Evaluation of Selected Handling Functions of Mechanical Control," Technical Report A-78-3, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

b. Productivity of the cutter and harvester machines with the processed plant material being returned to the water body.

c. Productivity of the cutter, harvester, and two tank barges in removing plant material from the water body.

d. Productivity of tank barges.

7. A secondary objective of the study was to identify additional research opportunities with the Limnos harvesting system that would permit improvements of the system itself as well as developing improved methods for field evaluation and identifying areas for future research.

8. Part II of this report describes the field test program including (a) the Limnos harvesting system used in the tests, (b) the test sites, and (c) the productivity tests using the Limnos system. Part III presents the productivity tests results of each/or combinations of each major component of the system (cutter, cutter and harvester, and tank barges). Part IV presents future research needs (improvements to the Limnos system, in-water disposal of processed plant material, and development of a systems model). Part V presents the conclusions and recommendations.

PART II: FIELD TEST PROGRAM

9. The mechanical control of submersed aquatic plants has been limited by the availability of productive cost-efficient harvesting systems. Mechanical harvesting costs have not been properly documented in the past with respect to the effect of environmental variables such as density of plant growth, means of disposal, size of area cut, and variable economic inputs, such as, cost of original equipment, operational cost (wages, fuel, repairs), and downtime. Previous mechanical control cost figures reported range from $80 to $800 per acre.* Due to the combination of low harvesting productivity and large variable cost rates per acre, the practical application of mechanical harvesting as a safe and beneficial control procedure has been greatly limited.

10. In a program designed to improve the productivity and cost effectiveness of mechanical control, the WES issued an RFP for the "Design, Manufacture, Test and Delivery of One or Two Mechanical Weed Control Systems." The purpose of this request was to promote interest in improved harvester designs from private industry. Evaluation factors and a technical committee were used to make the final selection of the contractor. Previous experience, as discussed in the preceding section, was invaluable in preparing the RFP and in evaluating the responses from industry. The Limnos Mechanical Harvesting System was selected, and on 3 February 1979 a contract was issued to Limnos Limited. The harvesting system was delivered to Wildwood, Fla., during the week of 16 July 1979 with the field test programs beginning shortly after assembly and operational checkout.

Limnos Harvesting System

11. The Limnos harvesting system utilizes a two-stage system in which submergent plants are cut at a selected depth by an independent cutter machine and allowed to rise to the surface. The harvester, following the cutter at a distance of about 100 ft, gathers the plants from near the water surface, grinds them to a slurry, and either drops the fluidized product into the opening of an attached barge or returns it to the water. When loaded, the barge

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* A table of factors for converting U. S. customary units of measurement to metric (SI) is presented on page 3.

is released, an empty one is "plugged-in," and harvesting continues. The loaded barge proceeds to the shore, or designated storage area, where it is off-loaded by means of a self-contained slurry pump. The technical specifications of the Limnos harvesting system are given in Appendix B of this report.

Cutter

12. Cutting of the submergent (hydrilla) plants is accomplished by a separate machine as shown in Figure 1. The cutter is powered by a

Figure 1. Limnos cutter

27 horsepower (hp) John Deere diesel tractor. The cutter knife assembly cuts an 18-ft swath to a maximum depth of 8 ft. The cutter bar is rear-mounted for accurate cutting and is free swinging to reduce damage from underwater obstructions. Internal hydraulics of the tractor are used to drive a sickle bar-knife cutter assembly designed for aquatic plant use. Cutting depth is controlled by raising and lowering the cutter bar that is attached to the standard implement control arm on the tractor.

13. Propulsion for the cutter is provided by the tractor through axle-driven paddle wheels. Eight forward gear combinations are available that cover all speeds required for cutting and running operations. Therefore, proper (1900) engine revolutions per minute (rpm) can be maintained to provide the necessary hydraulic fluid flow to oscillate the sickle bar at approximately 475 cycles per minute for a complete cut of all plants encountered. Steering is accomplished by a rudder attached to the tractor steering wheel

and by the independent wheel brakes. The wheel brakes are normally used for turning at the end of the cutting area. The cutter will turn in a distance approximately equal to its own length (20 ft) if the cutter bar is raised.

Harvester

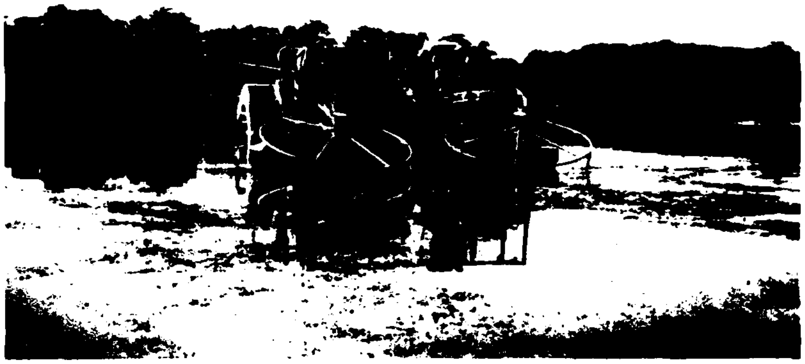
14. The Limnos harvester is shown in Figures 2a and 2b. It is powered by a John Deere Model 4240 diesel agricultural tractor (110 hp). The internal tractor hydraulics are used to power the gathering wheels and the elevator/conveyor, and to lower and raise the gathering wheels and forward edge of the elevator/conveyor into and out of the water. The harvester includes a processor (hammermill) which is driven at 1800 rpm by the tractor power takeoff. Similar to the cutter, the normal tractor gear drive and rear axles are used to power the paddle wheels.

15. Forward speeds of the harvester are controlled by the transmission gear selection. As discussed for the cutter, the harvester engine speed is maintained at approximately 1900 rpm to provide appropriate speeds for the hydraulically driven components and for the processor. The harvester has 12 possible forward gears, but most operations are conducted using gears A1, A2, and A3. The harvester can be stopped or reversed in the water by simply moving the tractor transmission gear selector to a reverse position.

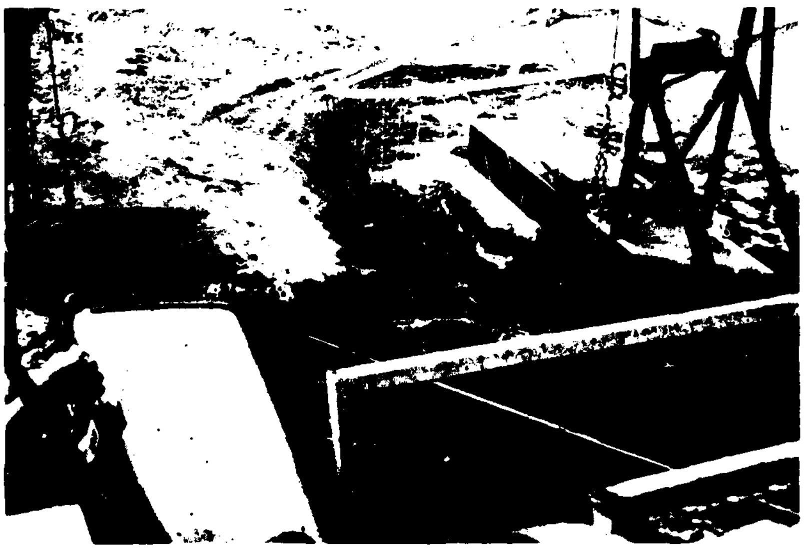
16. Steering maneuvers are performed by applying the tractor wheel brakes as discussed with the cutter. Rudders provided on the harvester are relatively ineffective, and most steering maneuvers are accomplished using the brakes. Without a barge, the harvester can negotiate a 180-deg turn in approximately 1 to 11/2 times its own length (30 to 45 ft). When a barge is attached, steering becomes more difficult and maneuvers must be anticipated considerably in advance. Approximately 100 ft is required to turn the harvester 180 deg with a nearly full barge attached.

17. The harvester (Figure 2) follows approximately 100 ft behind the cutter during a control operation. After the plants are cut and before they are harvested, the detached plants float to the water surface where the harvester removes them. This allows the pickup unit to operate at a relatively shallow depth, reduces the drag on the harvester, permits higher forward speeds, and thereby increases productivity.

18. The two gathering wheels of the harvester (Figure 2b) move the floating plants into an elevator/conveyor that removes the plants from the water. The 11-ft-diam gathering wheels collect floating plants and deposit



a. Harvester in operation



b. Closeup view of conveyor and gathering wheel

Figure 2. Limnos harvester

them in front of a 7.5-ft-wide elevator/conveyor, thereby increasing the effective harvesting width of the machine. Normally the gathering wheels are adjusted to provide an effective harvesting width of 18 ft.

19. Increasing the operating width (18 ft) to utilize the full machine capacity normally increases productivity more than maintaining a smaller width and increasing the forward speed of the machine. However, in several tests, 18 ft was found to be an unworkable width due to the high in situ plant densities that caused clogging and lengthy downtime. Therefore, the width was reduced to 6 ft which reduced the downtime and resulted in increased productivity.

20. The rotating speed of the gathering wheels and the elevator/conveyor linear speed can be adjusted by the operator using a single hydraulic control. Operator experience is required for proper selection of the optimum gathering wheel rotational velocity. Operating the wheels either too slow or too fast reduces plant pickup efficiency and may cause nonuniform pickup of plants or structural damage to the harvester.

21. The lower opening to the elevator/conveyor is 8.2 ft wide to allow more overlap with the gathering wheels. The 7.5-ft-wide elevator/conveyor was fabricated from steel mesh conveyor belting having a 1- by 1-in. mesh size. In operation, the elevator/conveyor extends approximately 2 ft below the water surface and lifts the plants 8 ft above the water for an overall length of 24.25 ft. Linear speed of the elevator/conveyor can be adjusted to a maximum of 2.6 ft/sec. Assuming that the speed of the elevator/conveyor does not change the plant pickup efficiency, changing the speed of the elevator/conveyor alters only the average length of plant segments discharged from the processor. In this regard, the speed of the elevator/conveyor could have an important effect on the viability of processed plant segments and the power requirements of the processor.

22. The Limnos harvester includes an onboard processor to alter the properties of the harvested plants. The processor, in this case a hammermill with a capacity of 30 to 50 tons/hr, chops the submergent plants into a viscous slurry that either falls into the attached tank barge for transport to a disposal site or returns the processed plants directly to the water body. The hammermill inlet is 8 ft wide, slightly wider than the elevator/conveyor. Two hammermill screens (1- and 2.25-in.-diam openings) were provided with the harvester. The larger (2.25-in.-diam) screen was used in all of the tests

reported here because of the relatively high rates of material passing through the hammermill. Based on visual observation, the average plant segment length was approximately 0.25 in.

23. Three potential benefits are gained from this type of onboard processor. First, the volume of aquatic plant material is reduced with a corresponding increase in density (from approximately 18 to 62 pcf). If the plants are being completely removed from the water body, the increased density in the tank barge reduces the volume of material that must be transported. Therefore, the productivity and capacity of the attached transport barge are increased, which also increases total system productivity. The second advantage is that the chopped material that falls directly into an attached tank barge can be removed by the use of pumps. Pumps are typically more flexible, reliable, and productive than either chain conveyors or augers. Furthermore, the chopped material in tank barges can then be transported over water to remote disposal areas at fairly high rates of speed using conventional inboard propulsion systems. The third major advantage achieved with the Limnos processor is that the chopped plant material can be returned directly to the water body, assuming that the chopped material has minimal impact on water quality and plant regrowth. With proper processor design and/or operation, it is possible that the viability of the plant particles can be reduced, thereby decreasing the danger of increasing or spreading nuisance plants.

Tank transport barges

24. Two tank barges, Figure 3, are normally included with the Limnos harvesting system. If plants are being removed from the water body, a barge is coupled to the harvester so the processor discharges the chopped plants directly into the barge. When the barge is full (approximately 18 tons or 4300 gal of chopped plant material and water), it is uncoupled, the second (empty) barge is coupled to the harvester, and the loaded barge proceeds to an unloading point near the shore. The tank barges are powered by 130 hp (maximum) diesel Volvo Penta inboard/outboard drive systems. With these units, the loaded barge can move to the unloading point at reasonably high speeds (5 mph) and return unloaded to the harvester (8 mph). The plant material is then transferred from the barge, using a low pressure-high capacity liquid manure pump (1 ton/min), into a truck or onto the shore.

25. The liquid manure pump, located in the barge hold, is driven hydraulically by the Volvo engine. The bottom of the hold is sloped to aid in

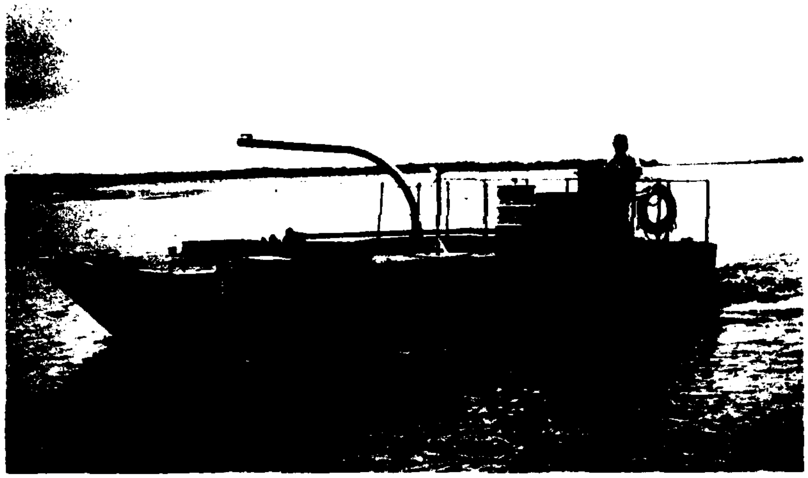


Figure 3. Limnos tank barge

moving the plant slurry to the pump inlet. It is also possible to divert the pump discharge back into the barge hold to agitate and stir the slurry, thereby aiding in moving the material to the pump inlet. However, in this test, an auxiliary water pump was added to each barge to supply fresh water to wash the slurry to the pump inlet. A 5-in. discharge pipe mounted on each barge provides the connection to the shore sections of 5-in. aluminum irrigation pipe carrying the slurry to the truck or disposal area.

26. Land transport of the plant material may be by any convenient and acceptable method (i.e. tank truck, liquid manure spreading wagon, etc.). Typically, the material is hauled to a landfill. However, the Limnos system delivers plant material in a form that it could be used for energy production or as a soil conditioner.

Test Area

27. Tests with the Limnos system were conducted on the Withlacoochee River located in central Florida in approximately the same locations as the tests described by *Culpepper and Decell (Aqua-Trio)* and Smith (low energy). Test locations are shown in Figure 4.

28. The Withlacoochee River Basin is a poorly drained area covering over 400 square miles. Numerous lakes and pond areas occur along the river.

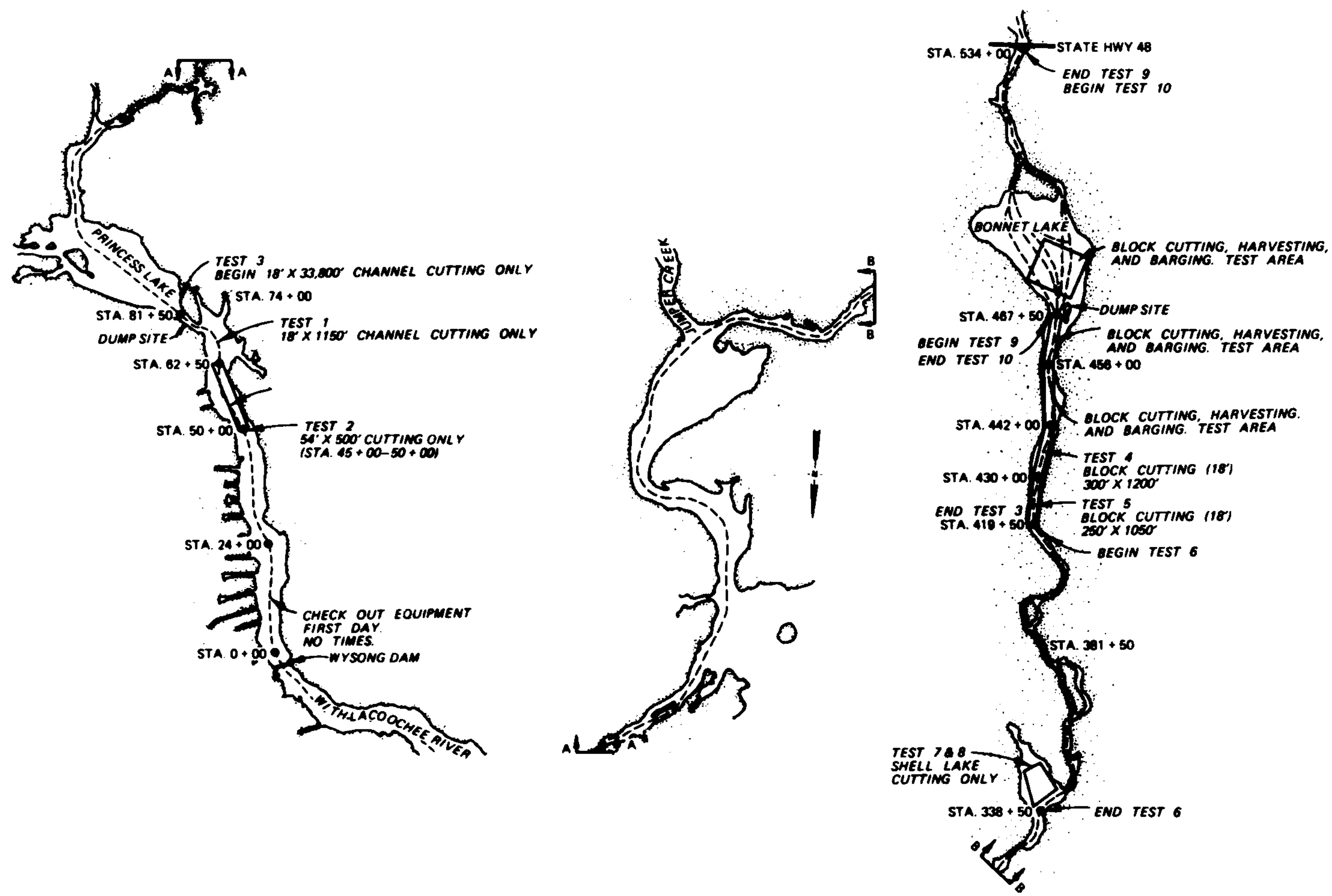


Figure 4. Plan view of Withlacoochee River test area

Typical water currents range from very slow to still. In the lakes and ponds the current is essentially zero, and the maximum current in narrow areas of the river is approximately 0.1 ft/sec. The river bottom is highly organic sand with numerous stumps and snags below the water surface.

29. Water depths typically range from 2 to 3 ft with approximately 0.5 ft of muck. Large areas within lakes are less than 2 ft deep, but areas in Bonnet Lake and along the narrow areas of the river are greater than 6 ft deep. A double cut procedure, cutting at a depth of 3 ft on the first pass through and at 6 ft on the second pass, was used in the deeper areas.

30. The predominant aquatic plant was hydrilla although some areas contained a mixture of hydrilla and waterhyacinth. At the time of the tests, the hydrilla were completely topped out. In situ plant densities averaged approximately 16 tons/acre. However, densities ranged from 2.5 tons/acre to greater than 30 tons/acre. Density values were based on the quantity of plant material removed by the harvester and accumulated in the tank barges. In areas where only the cutter was used or where processed plants were returned to the water body, the plant densities were based on visual estimates.

31. The general appearance of the river prior to a control operation is shown in Figure 5a. After harvesting, the waterway is improved as shown in the foreground of Figure 5b. Control operations permit the use of all types of watercraft in cleared areas.

Productivity Tests

32. The principal objective of this field test program was the contractor's 45-day operational field demonstration of the harvesting system. This was the third and final phase of the work requirement of the contract. Also, during this time, productivity data were collected and operational and maintenance training of Corps personnel was accomplished. Corps personnel supervised the test, laid out test areas, and collected data relating to the total system operation.

33. In one test, the productivity of the cutter machine operating alone was determined, in terms of the area covered per unit time. Productivity tests using the cutter and harvester working together in a cut, process, and return to the water body operation were also conducted. The third series of productivity tests consisted of the complete Limnos harvesting system (cutter,

a. Before cutting

b. After cutting

Figure 5. Appearance of test area before and after cutting

harvester, and two barges) barging the processed material to the disposal site. Productivity data on the tank barges were also collected.

Cutter

34. The Limnos cutter machine has the capability to cut an 18-ft swath to a depth of 8 ft. The depth of cut was controlled in some harvest areas to limit the quantity of material entering the harvester. This procedure required two or more cutting passes through an area to completely remove the plants. During the first stage of operation, plants within the site were cut to a depth of approximately 3 ft; during the second stage, they were cut to a depth of 6 to 8 ft. It was also necessary during some tests to reduce the cutting width of the plants as a result of high (J30 tons/acre) in situ plant densities. This was done by positioning the cutter such that it overlapped a position of the previous cut. Areas to be cut were measured (length, width, and depth) and markers placed in the water such that the cutter machine operator could determine where to start and stop the cutting. The time required to make each pass was recorded and used to compute the cutter production rate.

Cutter and harvester without barges

35. In the second series of harvester productivity tests, the harvester alone was used and the processed plants were returned to the water body. The harvester was operated with the collector wheels positioned for a plant removal width of 18 and 6 ft. Tests consisting of cutting, harvesting, processing, and returning the plant material to the water body were considered to be of major importance since the Withlacoochee River has few takeout points and since the river consists of narrow, straight and crooked sections interlaced with shallow, small and large lakes.

36. This method (cutting, processing, and returning to water body) of operation is considered to be the least costly way to control problem aquatic plants mechanically, but due to the lack of operational knowledge on oxygen depletion and other effects, it has not been used extensively. If proven successful, it would be ideal for cutting channels in the river and across sections of the lakes thereby providing access for boaters and fishermen. This method should also prove to be the most economical method for controlling problem plants and providing immediate access to water bodies.

Cutter and harvester with barges

37. Productivity tests using the complete Limnos harvester system (cutter, harvester, and barges) were conducted at various locations on the

Withlacoochee River. Sites were chosen such that a range of transporting distances could be obtained. The production rate using the transport barges is expected to be lower due to the fact that the barges have to be coupled and uncoupled from the harvester. The harvester stops operation during this time.

Tank barges

38. Productivity tests using the tank barges consisted of recording the distance traveled, time of travel, weight of plants, and unloading time. Production rates (tons per hour) can be calculated using the above data. The quantity of plant material transported was estimated by measuring the depth of plant material in the barge.

PART III: PRODUCTIVITY TEST RESULTS

39. The Limnos harvesting system was purchased as a complete submersed aquatic plant control system, consisting of a cutter, harvester with plant processor, and two tank barges. Even though it is considered a complete system, each major component of the system will be analyzed in this part of the report. This system has the capability of adapting to various environmental conditions (rivers, lakes) by using only the component(s) necessary to achieve the desired level of aquatic plant control. Therefore, the analysis of the data collected will be presented as "Productivity Test Results" of each major component of the entire system.

Cutter

40. Cutting tests were conducted in typical sections of the Withlocoochee River in terms of realistic conditions expected for routine operations in riverine and lake environments (i.e., stumps, snags, shallow water depth, etc.)

41. Results of cutter productivity tests are shown in Table 1. The average cutting rate, determined by the total area cut for the ten tests divided by the total time for the ten tests, was 4.06 acres/hr. The cutter average forward speed was 1.87 mph. This was determined by dividing the total of the distances traveled (test area length times the number of passes) by total time for the ten tests. The data for test 8 were adjusted to represent an equivalent to an 18-ft cutting width for consistency. Referring to Table 1, tests 1 and 2 were conducted at rates significantly lower than the remaining tests, which lowered the average productivity. These two tests were conducted to give the operators some experience with the cutting equipment; therefore, cutter productivity was lower than normal. Omitting the data from tests 1 and 2, the average productivity was 4.26 acres/hr with an average forward cutter machine speed of 1.96 mph. These values are considered more typical of the capability of the Limnos cutter. It should also be noted that the range of density of plants did not appear to have a significant effect on cutter performance. A total of 58.5 acres of hydrilla was actually cut during the cutting demonstration (10 tests).

42. Due to the variation in cutter production rates shown in Table 1, it is felt that an explanation is necessary. As stated above, tests 1 and 2 were

low because of operator training. Test 6 is lower than 5 or 7 because it was conducted in a typical riverine environment with many sharp turns and shallow depths throughout the test lane. A cutting width of 10 ft was chosen for test 8 because of the dense mat of topped-out hydrilla. (After analyzing the data and operational performance of this test, it is felt that the cutting of a narrow (10-ft) width is not an advantage in a cutting operation only.) A round trip cutting operation was conducted between Bonnet Lake and Highway 48; these data were used for tests 9 and 10, where the total values were divided equally for use in Table 1.

43. Data collected using the Aqua-Trio and other mechanical harvesting systems cannot be compared directly to the Limnos cutter since the systems are not identical. However, the Carver Aquatics cutter boat discussed in Report 2 by Smith had an average field production rate slightly less than 2.0 acres/hr. This cutter was much smaller (12-ft cutter bar) and lighter than the Limnos cutter. The system discussed by Culpepper and Decell (Report 1) had a harvesting rate variation of 9 to 15 tons per hour; therefore, absolute cutting data cannot be extracted since the cutter is part of the harvester. The horizontal cutter bar was only 8 ft long on this unit and was constructed similar to the other systems. Taking this into consideration, it is assumed that a cutting rate of approximately 2.0 acres/hr could be obtained with this unit also. When comparing the productivity of the above systems with the average of Table 1, the Limnos cutter is at least twice as efficient.

Cutter and Harvester

Without tank barges

44. Results of harvesting aquatic plants and returning the processed material to the water body are summarized in Table 2. The averages are obtained as in paragraph 41. Tests 1 through 10 were conducted while harvesting an 18-ft width of in situ plants.

45. Average productivity of the system using an 18-ft width was 1.70 acres/hr with an average forward speed of 0.78 mph. However, tests 2, 3, and 4 were conducted in areas having fewer toppedout (and lower densities) plants than the remaining tests. If these three tests are omitted, the average productivity was 0.97 acres/hr with an average forward speed of 0.44 mph. The latter values are more typical of areas with high density plants.

Difficulties with the gathering wheels were responsible for some of the reduction in productivity.

46. Reduction of the harvesting width to 6 ft resulted in an average productivity of 1.46 acres/hr with an average forward speed of 1.98 mph. Reducing the width of cut material to 6 ft increased the uniformity of material being delivered to the processor, and the overall operation of the onboard processor was improved. This demonstrates the need for having some preliminary data on in situ density to properly adjust harvesting components (throughput and speed) to achieve optimum harvesting performance.

47. The cutter productivity (paragraph 41) was significantly greater, i.e. more than double, than the productivity of the cutter and harvester operating together. Therefore, attempts to increase overall system productivity should focus on the various components of the harvester.

With tank barge

48. Test results obtained where the plants were cut, picked up, processed, and transported to the shore in barges are summarized in Tables 3 and 4. The averages are obtained similarly to those in paragraph 41. Table 3 includes data for the harvester, and Table 4 includes data for the barges.

49. The average production rate (Table 3) using the full 18-ft width of the harvester (tests 1 through 10) was 1.80 acres/hr with an average forward velocity of 0.82 mph. Based on the quantity of material in the tank barges, the average rate of processing was 7.51 tons/hr, and the average plant density in the water was estimated to be 4 tons/acre.

50. The next two series of tests were conducted using harvesting widths of 12 ft (tests 11 through 14) and 9 ft (tests 15 through 21). These two series of tests resulted in dramatic differences in productivity. The average production rate (Table 3) using the 12-ft width was 1.55 acres/hr with an average forward velocity of 1.06 mph. The average productivity rate using the 9-ft width was 0.33 acres/hr with an average forward velocity of 0.30 mph. Based on the quantity of plant material removed, the density of plants in the water was approximately 2.5 tons/acre with the 12ft width and 22 tons/acre with the 9-ft width.

51. Test numbers 22 through 31 were conducted by cutting and removing plants at two layer depths (0 to 3 and 3 to 6 ft deep) on successive passes with the cutter and harvester. Tests 28 and 31 represented third passes through the respective areas with the harvester to pick up plants remaining in

the water after the firststage tests. These tests were conducted in areas having moderate plant densities, averaging 8.2 tons/acre.

52. Tests 32 through 48 were conducted using an effective harvesting width of 6 ft. The productivity averaged 1.03 acre/hr with an average speed of 1.43 mph, and processing rate increased to 16.2 tons/hr. Based on the quantity of plants removed, the plant density was estimated to be 16.0 tons/acre. Productivity increased in these tests because, with the 6-ft cut, plant material was fed directly into the path of the elevator/conveyor, producing more uniformity of material into the plant processor.

53. The productivity of the harvesting system was not significantly affected by the use of an attached barge. The variability in the results can be attributed to variations in the density of plants in the water and operating difficulties caused by the gathering wheels not collecting the floating plant material and not placing it in front of the elevator/conveyor.

54. Performance of the harvester system as described in paragraphs 50 and 51 is probably not typical of its true capability. Except for tests conducted using the 9-ft width, the density of plants and operating procedure did not supply a sufficient quantity of material to the harvester to approach its capacity. In other words, operating procedures other than the ones used in these specific tests would have more nearly optimized the harvester's performance. More accurate methods of predicting plant density in the water would undoubtedly improve overall system performance and permit selection of the optimum harvester speed and cutting width for the plant density being encountered during the operations.

Tank Barges

55. The capability of the barges to transport the processed plant materials to shore is summarized in Table 4. The average barge load was 9.2 tons, and the average time required for the trip to shore with unloading was 37.9 min (0.63 hr). The average time for the round trip to shore with unloading was 48.5 min (0.80 hr). Material was unloaded at an average rate of 18.1 tons/hr, and the average overall barge productivity was 14.5 tons/hr. Barge productivity could have been increased significantly if the maximum capacity of 18 tons (for each barge) had been obtained (in these tests each barge was slightly over half full when it was taken to the shore unloading

point). Since two barges are required for continuous operation, larger loads and improved material handling capability would have improved the overall system efficiency. This further illustrates the need for thorough systems analysis when scheduling a harvesting operation.

56. The total time for each barge trip was not significantly affected by travel distance for the distances included in Table 4. Travel speeds were normally lower for the shorter travel distances, indicating that most of the time involved in each trip was used in unloading the plant material and other tasks having relatively fixed time requirements.

PART IV: SYSTEM PRODUCTIVITY IMPROVEMENT

57. It is apparent, in the author's opinion, that the Limnos Mechanical Harvesting System represents a technically advanced mechanical system for removal of submergent aquatic plants. The manufacturer's knowledge and experience gained from past work with agricultural machinery were well used in the design of the harvesting system. Standard diesel-powered farm tractors were used to drive the paddle wheels and to provide hydraulic power to the hydraulic motors. The tractor's power takeoff (P.T.O.) was used to operate the cutter bar and the plant processor unit. Proven liquid manure pumps were used to remove the slurry (processed plants) from the barges. The use of a hinged, rearmounted cutter allowed the cutter assembly to swing freely over bottom obstructions and virtually eliminated damage to the cutter knives. By using standard farm machinery, repair parts and service should be readily available in most locations.

58. However, during the test program described herein, several problem areas and/or potential modifications were identified. It is felt that three of these are worth incorporating into this portion of the report. These are: (a) improvement of the Limnos harvesting system, (b) evaluation of inwater disposal of processed plant material, and (c) development of a systems model.

Improvement of the Limnos Harvesting System

59. Modifications and/or areas where additional research might improve operation of the Limnos mechanical system are discussed below. It should be recognized that the recommendations outlined here do not alter the basic design concepts included in the Limnos system. Rather, the suggestions are specifically related to improving operation of the components included in the system.

Cutter

60. The Limnos cutter was generally satisfactory and its capacity exceeded that of the harvester. Reduction of the weight of the drive system (tractor) would reduce the fuel consumption of the cutter and thus decrease operating costs. Also, in dense plants, there was a tendency for the cutter bar to swing rearward due to increased drag. This resulted in the accumulation of plants on the cutter bar and reduced cutting efficiency. Redesign

of the cutter bar mount or spring tension clips on the cutter bar frame should alleviate this problem.

61. In dense and/or topped-out hydrilla, the sidemounted paddle wheels on the cutter unit caused considerable disturbance and dispersion of the plants. As the paddle wheels passed over and through plants, they tore plants from their stems. This prevented the cutter from making a clean cut behind the paddle wheels.

62. Interaction of the paddle wheels with the pontoons caused a lateral velocity component in the water. Plants disturbed by the paddle wheels therefore moved laterally away from the path of the harvester that was following behind. The result was that some of the plants were lost in the first-stage operation, causing a reduction in overall efficiency of the harvesting system in removing plants from the water.

63. The location and shape of the steering rudder on the cutter unit also reduced the effectiveness of the cut, particularly in dense plants. Plants tended to collect on the rudder, which pushed the in situ plants down in the water column and prevented them from being cut by the cutter bar. The result was that a narrow band of uncut plants was left in the water after harvesting. This problem could be easily corrected by simply removing the rudder since it is of minimal value in steering. Placement of rudders behind the two paddle wheels would also eliminate the problem and possibly provide increased maneuverability of the machine.

<u>Harvester</u>

64. Two components on the Limnos harvester should be further evaluated: the gathering wheels and the onboard processor. Also, as discussed with the cutter, a reduction in weight of the drive system (tractor) would probably reduce fuel consumption.

65. The gathering wheels permit an increase of the areal capacity of the harvester without increasing its basic size. However, the wheels used with the Limnos system were not as effective in gathering plants as is needed in areas of high plant densities. However, in some tests where the plant density was lower, the plants tended to pile up on the conveyor and overload the processor. This reduced the harvesting efficiency by causing shutdowns of the harvester.

66. The gathering units caused the plants to move both laterally (perpendicular to the direction of travel) and towards the moving

elevator/conveyor. The Limnos circular or wheel gathering units had a continuously varying forward speed, which depended upon the angular position of a specific point on the periphery of the wheel. Plants moved by the circular gathering wheels were thus subjected to accelerations, which made it somewhat difficult to move the floating plant in the water.

67. Careful adjustment of the position (width between gathering wheels and the angle of the wheel assembly with the water) of the harvester gathering wheels was required for satisfactory transfer of plants to the conveyor/elevator. The gathering wheels had to remove plants from the path of the harvester paddle wheels to prevent lateral dispersion as discussed previously for the cutter unit. Careful attention to the forward speed of the harvester is necessary to maintain uniform distribution of plants on the conveyor/elevator and into the processor.

68. Dense plants collecting on the gathering wheels increased the water drag on the wheels. This caused the leading edge of the gathering wheels to be deflected into the water and increased the forces on the structure supporting the gathering wheels. To prevent damage to the wheels and structure, operation of the harvester was modified by reducing the effective pickup width.

69. In very dense plants, the cutter and harvester should have the same effective operating width and depth. For example, if dense, topped-out plants are cut 4 ft deep, the plants or portions of plants near the 4-ft level cannot float to the surface because of the mat of plants at the water surface. Since the maximum operating depth of the Limnos conveyor/elevator is less than 2 ft (after field modification) and the gathering wheels operate less than 1 ft deep, a large quantity of plant material is left below the bottom edge of the conveyor/elevator. When the upper plants are removed from the 0 to 2-ft depth, underlying cut plants float to the surface. These loose plants are dispersed by the harvester paddle wheels, by wind, and by wave action and must be cleaned up by subsequent passes of the harvester.

70. The hammermill processor produces a slurry consisting of water and chopped plant materials. This changes the density of the plants and reduces the volume of material that must be handled. The possibility of further reducing the volume of material by dewatering the processed plants should be investigated. Also, use of a chopper to cut the plant material into small, discrete particles should be studied since chopping in general uses

considerably less energy. Tests should also be conducted to determine how the free water can be separated from the plant material and returned to the water body. Since aquatic plants often contain more than 90 percent water, removal of a small percentage of water would significantly reduce the volume and weight of material to be handled and transported.

Tank barges

71. Difficulties were experienced in removing the processed plant materials from the tank barges. Due to the nature of the chopped plants, they would not always flow downward to the pump inlet. Therefore, additional water was required to wash the material from the sides of the tank barge into the pump inlet, which increased the volume of mixed water and material that had to be removed and hauled away for land disposal.

72. The feasibility of two possible modifications should be studied. The first would be to alter the shape of the bottom of the barge and possibly add an auger conveyor to move the plant materials to the pump. Another possible solution would be to alter the processing unit (hammermill) so the plants could be conveyed or pumped more easily. The most appropriate solutions would depend on the required degree of processing and should be based on the properties of the processed plant materials.

Evaluation of In-Water Disposal of Processed Plant Material

73. Mechanical harvesting is the only method commonly used to control aquatic plants by physically removing the plants from the water body. In some situations, physical removal may be necessary. However, if the plants could be processed and returned to the water body with minimal impact in terms of water quality and regrowth potential, the harvesting operations would be improved and the labor and machine costs would be significantly reduced.

74. Research studies should be undertaken to evaluate the impact on water quality and regrowth potential of returning processed aquatic plants to the water body. Situations and/or circumstances should then be defined where total, partial, or no removal of processed plants could be used within the water body.

Development of a Systems Model

75. A computer model for systems analysis of the Limnos harvesting system was included as part of the contract with Limnos Ltd. The model of the harvesting system was developed to be used as a tool to improve the predictability of cost and production of mechanical control. The purpose of the initial model has been fulfilled and it is felt that major efforts should be directed towards development of an overall systems model that can be used to effectively plan mechanical harvesting operations.

76. Two significant inputs, not currently available, are required for the model. First, a method needs to be developed for obtaining an accurate aquatic plant density map of the projected harvest area. The map should indicate plant density with respect to area and layer depth such as 0 to 2, 2 to 4, 4 to 6 ft, etc. The plant density map would facilitate selection of appropriate machines, machine speeds (or gears), required capacities, and optimal methods of plant disposal for the harvesting program.

77. The second significant input required for the modeling effort is the relationship between the density of plants and the forward velocity of the harvester while operating under constant maximum capacity. In the model, the relationship would be used to optimize operation of the harvester. It could also be used in more sophisticated models to optimize mechanical design of aquatic plant harvesters and harvesting systems.

78. Evaluation of two additional factors would also enhance the value of a mechanical harvester systems model. These factors involve the cost and timeliness of required mechanical maintenance and the efficiency of harvesting various aquatic plants as a function of environmental conditions such as plant density, water speed, wind direction, etc. The significance of and appropriate values or functions for these factors should be developed as additional operating experience is accumulated.

PART V: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

79. The following conclusions are based on tests described in this report using the Limnos Mechanical Harvesting System for control of submergent plants (hydrilla):

- a. The Limnos cutter has a productivity average of 4.26 acres/hr with a forward speed of 1.96 mph (paragraph 41).
- b. The Limnos harvester removed and processed 1.46 acres/hr with a forward speed of 1.98 mph (paragraph 46) and a 6-ft operating width. The processing rate in hydrilla was approximately 16 tons/hr in a plant density of approximately 16 tons/acre (paragraph 52). The gathering wheels (which could increase operating width to 18 ft) did not, because of operating problems, increase productivity in areas of dense hydrilla.
- c. Each tank barge had an overall productivity of 14.5 tons/hr and an average total round trip time with unloading of 0.8 hr barge trip was not significantly affected by short travel distances.
- d. In typical operational environments for relatively short barging distances (i.e., when no harvesting delays resulted from long barging), overall system productivity averaged 15.1 tons/hr (1.38 acres/hr) (see paragraphs 48-54).

Recommendations

80. Recommendations are as follows:

- a. Improvements should be made to the Limnos harvesting system in the following manner:
  - (1) Redesign the mounts for the cutter bar and/or relocate the cutter bar (see paragraph 60).
  - (2) Remove the steering rudder on the cutter machine (see paragraph 63).
  - (3) Improve operation of the gathering wheels and associated mechanisms on the harvester machine (see paragraphs 65-68).
  - (4) Improve plant processing methods for further reduction in the quantity of material that must be handled and reduce power requirements (see paragraph 70).
  - (5) Modify the tank barges to facilitate movement of slurry to the pump inlet (see paragraphs 71 and 72).
- b. A study should be developed to estimate the impact of returning processed plant materials to the water body in terms of water

quality and regrowth potential (see paragraphs 73 and 74).

c. A systems model should be fully developed to assist in planning aquatic plant harvesting operations and to assist in selecting the optimum equipment for a specific harvesting operation (see paragraphs 75-78).

d. Improved methods should be developed for measuring the density of aquatic plants in the water column (see paragraph 3).

Table 1

Productivity of Limnos Cutter in Hydrilla Using 18-ft-Wide Cut

Test No.	Test Area Length ft	Test Area Width ft	Area Cut acres	Elapsed Time min	Cutter Rate acres/hr	Cutter Avg Forward Speed, mph	Cutting Width ft	Number Passes	Cutter Depth ft	Remarks
1	1,150	18	0.48	25	1.15	0.52	18	1	3-6	Downstream from Princess Lake
2	500	54	0.62	30	1.24	0.57	18	3	3-6	Downstream from Princess Lake
3	33,800	18	13.97	230	3.64	1.66	18	1	2-6	Channel cut up river (Princess Lake to Trails End Lodge)
4	1,200	300	8.26	117.7	4.21	1.93	18	17	4-8	Upstream from Trails End Lodge
5	1,050	250	6.03	65.5	5.52	2.53	18	14	3-6	Test plot north of Trails End Lodge
6	8,000	18	3.31	45	4.41	2.02	18	1	2-6	Channel cut downstream from Trails End Lodge to Shell Lake
7	820	720	13.55	119	6.83	3.1	18	40	3-6	Shell Lake
8	820	360	6.78	162	2.51	2.07	10	36	3-6	Shell Lake (very thick matted plants)
9	6,650	18	2.75	35	4.71	2.16	18	1	2-6	Channel cut upstream (Bonnet Lake to Highway #48)
10	6,650	18	2.75	35	4.71	2.16	18	1	2-6	Channel cut downstream (Highway #48 to Bonnet Lake)

Table 2

Productivity of Limnos Harvester in Hydrilla, Processed Plant Material Discharged to Water Body

Test No.	Test Area Length ft	Test Area Width ft	Area acres	Harvesting Time min	Harvesting Rate acres/hr	Harvesting Speed mph	Harvesting Width ft	Cutter Width ft	Number of Passes	Remarks
1	800	18	0.33	9.0	2.2	1.01	18	18	1	
2	1,800		0.74	4.5	9.87	4.55				
3	1,800		0.74	5.5	8.11	3.72				
4	1,800		0.74	4.5	9.87	4.55				
5	1,250		0.52	23.0	1.35	0.62				
6	1,150		0.48	38.0	0.75	0.34				
7	100		0.04	2.0	1.24	0.57				
8	1,250		0.52	51.5	0.60	0.28				
9	600		0.25	14.0	1.06	0.49				
10	600		0.25	10.25	1.46	0.67				The 0- to 300-ft length was cut with a 3-ft depth of cut and the 300- to 600-ft length was cut with a 6-ft depth of cut
11	1,000	6	0.14	5.0	1.65	2.27	6	6	1	
12		6	0.14	4.5	1.87	2.52			1	
13		30	0.69	25.0	1.65	2.27			5	
14		6	0.14	10.5	0.80	1.08			1	
15				4.75	1.77	2.39				
16				5.0	1.68	2.27				
17				5.08	1.65	2.24				
18				5.25	1.60	2.16				
19				5.75	1.46	1.98				
20				6.25	1.34	1.82				
21				7.0	1.20	1.62				
22				6.0	1.40	1.89				
23				5.5	1.53	2.07				
24				6.75	1.24	1.68				
25				6.0	1.40	1.89				
26				6.9	1.22	1.65				
27				5.25	1.60	2.16				
28				6.0	1.40	1.89				

Table 3

Productivity of Limnos Harvester in Hydrilla, Processed Material Barged to Shore

Test No.	Test Area Length ft	Test Area Width ft	Area acres	Biomass Harvested tons	Harvesting Time min	Harvesting Rate acres/hr	Harvesting Rate tons/hr	Harvesting Speed mph	Harvesting Width ft	Number of Passes	Remarks
1	1,250	18	0.5	7.74	22.75	1.31	20.4	0.62	18	1	
2	650	18	0.27	5.35	18.33	0.88	17.51	0.40		1	
3	1,100	18	0.45	11.85	38.00	0.72	18.71	0.33		1	
4	1,400	54	1.74	8.22	32.70	3.18	15.09	1.46		3	
5		72	2.31	8.22	43.60	3.18	11.31	1.46		4	
6		54	1.74	2.91	32.70	3.18	5.34	1.46		3	
7		90	2.89	8.72	108.05	1.61	4.84	0.73		5	
8				8.72			4.84				
9				7.22			4.01				
10				8.72			4.84				
11	1,150	144	3.80	9.22	147.48	1.55	3.75	1.06	12	12	
12				9.73			3.96				
13				10.00			4.07				
14				9.73			3.96				
15	1,000	27	0.62	9.75	112.50	0.33	5.2	0.3	9	3	
16		27	0.62	8.21	112.50		4.38			3	
17		18	0.41	9.74	75.00		7.79			2	
18				10.80			8.64				
19				11.33			9.06				
20				11.85			9.48				
21				10.80			8.64				
22	2,700		1.12	—	45.00	—	—	0.68	18		Cut to a 3-ft depth
23					45.00			0.68			Same area as 22, cut 6 ft deep
24					30.78			1.0			Cut to a 3-ft depth
25					30.78			1.0			Same area as 24, cut 6 ft deep
26					36.70			0.84			Cut to a 3-ft depth
27					36.70			0.84			Same area as 22, cut 6 ft deep
28					36.70			0.84			Clean up same area as 26 and 27
29					13.37			2.29			Cut to a 3-ft depth
30					13.37			2.29			Same area as 29, cut 6 ft deep
31					13.37			2.29			Clean up same area as 29 and 30
32	1,000	18	0.41	8.22	13.83	1.79	35.7	2.46	6	3	
33		36	0.83		30.91	1.60	15.96	2.21		6	
34		42	0.96		46.66	1.23	10.6	1.70		7	
35		18	0.41		14.25	1.74	34.62	2.39		3	
36		12	0.28		10.33	1.60	47.75	2.20		2	
37		36	0.83	7.73	25.60	1.94	18.11	2.66		6	
38		45	1.03	9.74	19.50	1.38	29.97	2.91		8	
39		42	0.96	9.74	33.50	1.73	17.45	2.37		7	
40		30	0.69	9.74	24.50	1.69	23.86	2.32		5	
41		30	0.69	8.72	21.50	1.92	24.33	2.64		5	
42		24	0.55	7.73	19.00	1.74	24.40	2.39		4	
43		24	0.55	9.21	16.00	2.07	34.55	2.84		4	
44		24	0.55	7.73	18.00	1.84	25.75	2.53		4	
45		180	4.13	84.22	348.00	0.71	14.52	0.98		30	
46		50	1.15	34.86	153.00	0.45	13.67	0.67		9	
47		150	3.44	43.18	204.50	1.01	12.67	1.39		25	
48		180	4.13	65.32	257.50	0.96	15.22	1.32		30	

Table 4

Barge Productivity with Limnos Harvester

Test No.	One Way Transport Distance ft	Transport Time min	Transport Rate mph	Plant Biomass lb	Unload Time min	Unload Rate tons/hr	Time to Transport to Shore and Unload min	Productivity tons/hr	Total Time min	Remarks
1	2,000	18.33	1.24	15,400	10.17	45.6	28.0	16.3	34.5	
2	2,000	17.00	1.34	10,700	8.00	40.1	25.0	12.8	30.0	
3	--	--	--	23,700*	--	--	--	--	--	Mechanical problems
4	2,250	11.00	2.32	16,400	33.00	14.9	44.0	11.2	55	
5	2,250	11.00	2.32	16,400	33.00	14.9	44.0	11.2	55	
6	2,250	8.00	3.20	5,820	25.00	7.0	33.0	5.3	55	
7	3,650	12.00	3.46	17,400	31.00	16.9	43.0	12.1	53	
8	3,650	9.00	4.61	17,400	36.00	15.5	45.0	11.6	55	
9	3,000	11.00	3.10	14,500	37.00	11.7	48.0	9.0	56	
10	3,000	10.00	3.41	17,400	45.00	11.6	55.0	9.5	67	
11	200	4.00	0.57	18,400	56.00	9.9	60.0	9.2	64	
12	200	6.00	0.38	19,500	46.00	12.7	52.0	11.2	57	
13	1,400	8.00	1.99	20,000	59.00	10.2	67.0	9.0	75	
14	1,400	9.00	1.77	19,500	44.00	13.3	53.0	11.0	62	
15	225	6.00	0.43	19,500	44.00	13.3	50.0	11.7	54	
16	1,425	7.00	2.31	16,400	39.00	12.6	46.0	10.7	53	
17	225	5.00	0.51	19,500	40.00	14.6	45.0	13.0	50	
18	1,250	8.00	1.78	21,600	41.00	15.8	49.0	13.2	56	
19	225	5.00	0.51	22,600	40.00	17.0	45.0	15.1	50	
20	1,225	7.00	1.99	23,700	48.00	14.8	55.0	12.9	63	
21	225	4.50	0.57	21,600	39.00	16.6	43.5	14.9	49	
22	Same harvester test as No. 23 (No. 22 and 23 one barge)									
23	600	7.00	0.97	20,500	37.0	16.6	44.0	14.0	50	
24	Same harvester test as No. 25 (No. 24 and 25 one barge)									
25	200	4.00	0.57	16,400	35.0	14.1	39.0	12.6	44	
26	Same harvester test as No. 28 (No. 26, 27, and 28 one barge)									
27										
28	200	3.00	0.76	17,400	36.0	14.5	39.0	13.4	45	
29	Same harvester test as No. 31 (No. 29, 30, and 31 one barge)									
30										
31	200*	--	--	19,000*	--	--	--	--	--	
32	600*	--	--	16,400*	--	--	--	--	55*	
33	600*	--	--	16,400*	--	--	--	--	35*	
34	600*	--	--	16,400*	--	--	--	--	--	
35	600*	--	--	16,400*	--	--	--	--	--	
36	600*	--	--	16,400*	--	--	--	--	--	
37	--	--	--	15,400*	--	--	--	--	--	Unloaded after 5-day wait
38	1,000	7.50	1.52	19,400	34.0	17.2	41.5	14.1	48	
39		3.00	3.79	19,400	39.0	15.0	44.5	13.1	48	
40		4.00	2.84	19,500	38.0	15.4	42.0	13.9	45	
41		3.00	3.79	17,400	36.0	15.5	39.0	13.4	41	
42		8.00	1.42	15,500	36.0	12.9	44.0	10.5	60	
43		2.00	5.68	18,400	17.5	31.6	19.5	28.3	23	
44		16.50	0.69	15,400	15.0	30.9	31.5	14.7	64	
45a	600	10.00	0.68	17,400	13.0	40.3	23.0	22.7	43	Harvester test 45
45b		4.00	1.70	12,500	18.0	20.8	22.0	17.0	30	
45c		7.00	0.97	17,400	20.0	26.1	27.0	19.3	41	
45d		7.00	0.97	17,400	31.0	16.9	38.0	13.7	52	
45e		4.00	1.70	15,400	31.0	15.0	35.0	13.2	43	
45f		7.00	0.97	18,400	21.0	26.3	28.0	19.7	42	
45g		7.00	0.97	16,400	25.0	19.7	32.0	15.4	46	
45h		5.00	1.36	12,500	16.0	23.3	21.0	17.8	31	
45i		3.00	2.27	18,400	36.0	15.3	39.0	14.2	45	
45j		3.00	2.27	24,700	40.0	18.6	43.0	17.2	49	
46a	800	3.00	3.03	17,400	24.0	21.8	27.0	19.3	33	Harvester test 46
46b	800	9.00	1.01	16,400	35.0	14.1	44.0	11.2	62	Harvester test 46
46c	800	16.00	0.57	17,400	20.0	26.1	36.0	14.5	68	Harvester test 46
46d	200	1.00	2.27	18,400	25.0	22.1	26.0	21.2	28	Harvester test 46
47a	1,000	8.00	1.42	23,700	19.0	37.4	27.0	26.3	43	Harvester test 47
47b		6.00	1.89	20,500	24.0	25.7	30.0	20.5	42	Harvester test 47
47c		6.00	1.89	18,400	20.0	28.7	26.0	21.3	38	Harvester test 47
47d		5.00	2.27	23,700	24.0	29.6	29.0	24.5	39	Harvester test 47
48a		5.50	2.07	23,700	19.0	37.4	24.5	29.0	35	Harvester test 48
48b		11.00	1.03	24,700	20.0	37.1	31.0	24.0	53	
48c		6.00	1.89	20,500	21.0	29.3	27.0	22.8	39	
48d		21.00	0.54	20,500	20.0	30.8	41.0	15.0	83	
48e		5.50	2.07	21,600	23.0	28.1	28.5	27.7	39	
48f		5.50	2.07	19,500	19.0	30.7	24.5	23.8	35	

Note: Average rate of transport to shore, 1.67 mph
Average barge load, 9.2 tons
Average unloading rate, 18.1 tons/hr
Average time to transport load to shore with unloading, 37.9 min (0.63 hr)
Average barge productivity, 14.5 tons/hr
Average total time for round trip to shore wit! unloading, 48.5 min (0.80 hr)
* Not used in computing final average values.

APPENDIX A: STATEMENT OF WORK FOR DESIGNING, DEVELOPING, MANUFACTURING, TESTING, AND DELIVERING MECHANICAL AQUATIC WEED CONTROL SYSTEM(S)*

Background Information for Work to be Done

1. The U. S. Army Engineer Waterways Experiment Station is planning and conducting research for the Chief of Engineers and the U. S. Army Engineer District, Jacksonville, on the development of mechanical systems for the control of problem floating and submersed aquatic plants. To date, most mechanical control systems available are too energy intensive to be cost-effective in terms of the per acre cost to effect acceptable control. Collecting and/or transporting the plants to a takeout point at the water-land interface or at an approved disposal area in the water body have been a major obstacle in arriving at an efficient, high-capacity plant control system. Further, recent research suggests the development of less energy intensive systems can be effected only if they are well suited to the physical characteristics of the major environments in which the problem plants usually occur. Because the performance of mechanical methods of aquatic plant control is highly sensitive to the physical environment in which they operate, care must be taken to ensure that the mechanical components that comprise any system can be operated in such a manner that a cost-effective operational mix for controlling aquatic plants in a given environmental context results.

Scope of Work

2. The work to be done under this contract involves the design, fabrication, and demonstration of one or two systems for the mechanical control of floating and submersed aquatic plants. The work shall be accomplished by the Contractor in three phases: design formulation, fabrication, and field demonstration. The first phase shall consist of the formulation of the design of the system(s). After evaluation and Government approval of these designs, the second phase shall consist of the fabrication of the system(s). The third phase of the work shall consist of field demonstration of the system(s) in two environmental contexts.

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* Statement of work from RFP No. DACW39-78-R-0008.

Environmental context

3. While it is recognized that mechanical methods of control are highly site sensitive, implying an individual system for each different environment, it is also recognized that present technology could possibly provide one system that would operate effectively in multiple environments, with only minor modifications. An idealized description of the two environments in which the equipment will be required to operate is described in the following paragraphs.

4. Environment 1. This environment is characterized by the following quantitative and qualitative descriptors:

a. Water body width--20 ft to 6 miles

b. Water velocities--0 to 0.25 ft/sec

c. Water depth--1 to 30 ft

d. Wind vector, 0600-1400 hr--0 to 3 mph from 20 deg
1400-2000 hr--0 to 8 mph from 270 deg

e. Bank angles--15 to 60 deg

f. Shoreline development ranges from undeveloped to intensively developed. Several areas consist of towns and small cities in addition to privately owned waterfront homes, marinas, and fishing camps. The undeveloped portions are characterized by hardwood swamps and some marshlands.

The target problem aquatic plant in this environment is the waterhyacinth (Eichhornia crassipes (Mart.) Solms). In situ densities of this plant range from 40 to over 150 tons per acre. Distribution of the plant is predominately aligned with and along the shoreline, not necessarily continuous. Individual plants and mats of various sizes are continually moving about in the water body, which is influenced by tidal action, in a direction and rate coinciding with the current and/or wind, whichever is predominant.

5. Environment 2. This environment is characterized by the following quantitative and qualitative descriptors:

a. Water body width--20 ft to 2 miles

b. Water velocities--0 to 0.20 ft/sec

c. Water depth--1 to 8 ft

d. Wind vector, 0600-1200 hr--0 to 4 mph from 40 deg
1200-2000 hr--0 to 6 mph from 240 deg

e. Bank angles--15 to 60 deg

f. Shoreline development ranges from undeveloped to sparsely developed, the developed areas consisting primarily of fishing camps and private homes.

The target problem aquatic plant in this environment is hydrilla (Hydrilla verticillata Royle). In situ densities of this plant range from 8 to 20 tons/acre for the indicated depth ranges. This plant is a submerged rooted plant. The distribution within the water body is along and parallel to the shoreline with growths progressing outward from the shoreline for several hundreds of feet, often meeting in the middle of the water body. Periodically, mats of waterhyacinths can be found floating on top of the target plant. Mats of these hyacinths move about the water body, often with mats of the target plant entangled in the hyacinth root system. This water body is not influenced by tidal action; thus, any flow is generally in a northerly direction.

6. To control both of these environments, there is a possibility that two separate systems may be required which may or may not be similar as a result of environmental considerations. Evaluation of offers will be based on both working conditions and may result in two separate awards. Proposals may be submitted on the basis of one or both environmental situations.

7. The field demonstration acceptance tests shall be of sufficient duration to simulate plant control operations. The equipment shall be operated for a minimum of 45 calendar days in each environmental condition. All materials and labor necessary to perform these tests shall be furnished by the Contractor.

Desired performance characteristics

8. The mechanical control system(s) shall be designed such that performance is maximum when operated in the two idealized environments described in the previous paragraphs; however, it is desirable that the system(s) be able to operate in other plant infestations found in environmental conditions that closely fit the descriptions of the two idealized environments. Other minimum performance criteria include:

a. In Environment 1, the system shall provide an overall system output of not less than 60 tons of the target plant per hour at the disposal point.

b. In Environment 2, the system shall provide an overall system output of not less than 30 tons of the target plant per hour at the disposal point.

c. Disposal of plant material shall be effected in such a manner that (1) the material is reduced to approximately 15 percent of its original bulk volume within 45 days, (2) the State of Florida standards for water quality as set forth in the Florida Department of Pollution Control Rules, Chapter 17-3, are not violated, and (3) the material poses no other adverse environmental effects

at the disposal site proper.

d. During system operation, the mechanical system(s) shall not adversely interfere with water body uses such as navigation, fishing, boating, and water recreation.

e. The system(s) shall effect control of submersed plants to the maximum depth possible, but not less than 5 feet.

f. The system(s) shall be able to operate at the desired efficiency in environments where the wind prevails at velocities of up to 15 mph.

g. The system(s) shall comply with all applicable Coast Guard and Occupational Safety and Health Administration regulations.

Test phases

9. The work was divided into the following phases:

a. Phase 1, Design Formulation. The contractor(s) shall provide the design(s) of the proposed mechanical system(s) in sufficient detail such that the Government can evaluate the concept in quantitative terms. The design(s) will be reviewed and approved or rejected by the Government with the Jacksonville District.

b. Phase II, Fabrication. Any changes during this phase that would reflect a change in concept shall be approved by the Government prior to effecting.

c. Phase III, Field Demonstration. The Contractor shall demonstrate the system for a period of at least 45 calendar days in each environment for which it is designed. This period is deemed necessary in order to simulate operational control of activities required by the Jacksonville District. The locations for the field demonstrations will be selected from specified problem areas of the St. Johns River (Environment 1) and the Withlacoochee River (Environment 2) in Florida. Site easements, including arrangements for water and/or land disposal locations, will be accomplished by the Government. Final site selection will be accomplished jointly by Government personnel from the WES, Jacksonville District, and the Contractor. The Contractor(s) shall use primarily in-house capabilities and expertise in formulating the design and fabrication of the system(s).

APPENDIX B: TECHNICAL SPECIFICATIONS AND PARTS LIST FOR THE LIMNOS MECHANICAL HARVESTING SYSTEM

Specifications

Cutter Unit	
Length:	20'0"
Width (Hull):	10'0"
Draft:	1'5"
Power: John Deere 950 Diesel:	27 hp
Cutting Width:	18'0"
Cutting Depth:	0 to 8'0"
Paddle Wheel Diameter:	6'0"
Paddle Wheel Width:	2'6"
Steering: Rudders and Independent Wheel Brakes	
Weight:	5.0 tons
Speed Traveling	5.5 mph
Speed Cutting	3.5 mph
Construction Material: Steel	
Harvester Unit	
Length (Hull only):	30'0"
Width (Hull): Operating Mode	17'6"
Width (Hull): Transport Mode	11'10"
Draft:	2'0"
Power: John Deere 4240 Diesel:	110 hp
Paddle Wheel Diameter:	8'0"
Paddle Wheel Width:	2'6"
Steering: Power Steering to Rudders and Independent Wheel Brakes	
Weight:	10.0 tons
Speed Not Harvesting:	6.0 mph
Speed Harvesting:	3.5 mph
Maximum Collecting Width:	28'0"
Collector Wheel Diameter:	11'0"
Conveyer Width:	8'2"
Hammermill Throat Width:	8'0"
Construction Material: Steel	
Tank Barges (2)	
Length:	30'0"
Width:	10'0"
Draft: Light:	10"
Loaded:	2'10"
Power: Volvo Penta Inboard/Outboard AQ D40A/280B Max. H.P. 130, Continuous:	90 hp
Pump: Liquid Manure Pump Unloading (15 tons):	15 min
Pump Drive: Hydraulic to Volvo Engine	
Slurry Tank Capacity:	18 tons
Weight (Empty):	4.5 tons

Construction Material: Steel
Finish: Base Coat Inside and Out. Finish Coat
Mid-green, Yellow Trim
Pipe Barge to Truck: Aluminum Irrigation: 5"

Parts List

Cutter

Paddlewheel Axle Bearings: Dodge 2-15/16" split babbited journal bearings
Paddle Hub Bolts: metric 16 mm × 60 mm hex cap screws and jamb nuts, 2.0 pitch
Lift Cylinder: Monarch 3" × 16" 2-way implement cylinder
Cutter Drives: 2-5/8" rod end bearings Heim-Incom International Inc. Fairfield, Conn.
Knife: 18' Kwick-cut bar Cat. #1010682, White Farm Equipment, Oakbrook, Ill.
Motor: Char-Lynn, 101-1001-007

Harvester

Collector Wheels
Top Bearing: NTN 1-1/4" Velp 207 bearings
Bottom Bearing: NTN 1-1/4" UCP 207
Chain: #40 Roller chain
Sprockets: #40 × 14 tooth × 1"
#40 × 80 tooth × 1-1/4"
Spokes: .312 Dia. S P S. CD RD
Motor: Char-Lynn #101-1007-007

Grinder
Main Bearings: NTN, UCFS, 312-2-3/8"
Countershaft Bearings: NTN UCP-212-2-3/8"
Pulleys: 6C9.0 sheaves-bottom-machined
Top-RX 2-3/8" bushing
Belt: 3RC 173 banded
Coupler: Lovejoy L225-2-3/8" × 2-3/8"
Gearbox: Ford E31541
Screens: Bear Cat, Western Land Roller Co. Hastings, Nebr.

Conveyer
Flat Wire Belting: 1" × 1" clinched edge. Cambridge Wire Cloth Co., Cambridge, Md.
Bearings: NTN-UCP 207-104 (1-1/4")
Motor: Char-Lynn 103-1006
Chain Coupler: 5016 chain coupling 1" × 1-1/4"
Winches: Fulton #594
Bumper Wheels: Standard wheelbarrow wheels

Barges

Engine: Volvo Penta AQD 40A - Outdrive 280B
Pump and Drives

Hydraulic Pump: Tyrone #P2-95-6-D-4-D
Hydraulic Motor: Borg-Warner #G30S-17-AS-2-5B
Valve: Douglas RDRS 175
Filter: SGF2
Coupling: Hayes 40 Series 1-3/8" shaft
Fluid: Harmony 54 - Gulf
Liquid Manure Pump: Husky Farm Equip., Alma, Ont. Bearings: Budd Co.

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